VOYAGE TO THE HEART OF A COMET

Comets occasionally give us dazzling light displays in the night sky, but they may also help us to understand the chemical processes that led to our existence on Earth.

A little more than a decade ago, a mission was sent to view a comet up close. The European spacecraft Giotto flew by Comet Halley in 1986, and in 1994, when Comet Shoemaker-Levy 9 smashed into Jupiter, the Galileo spacecraft gave us our first clear images of such a cataclysmic planetary event. These investigations offered new evidence that comets have played an important role in the development of our solar system. By analyzing the light from comets (using a method called spectroscopy), scientists have found out that they contain water, methane, and organic molecules—three ingredients necessary to support life.

What role did comets play in the formation of planets? How did comets affect the emergence of life on our planet? What role will comets play in Earth's future? The easiest way to answer these questions would be to step back about 4.5 billion years to the time when our solar system was being formed. Much of the primordial material from that time has been preserved in comets—the debris left over from the formation of the solar system.

At NASA's Jet Propulsion Laboratory, scientists are designing the first mission to land on a comet. Space Technology 4 (ST4) /Champollion will function as a virtual time machine, taking us back for our first look at the materials that existed when Earth and the solar system were forming. The material that makes up comets has been undisturbed since the beginning of the solar system, frozen into icy chunks far away from the chemical reactions that are plentiful on the much warmer planets. ST4/Champollion will be launched in 2003 to visit Comet Tempel 1. The spacecraft will carry a small probe that will land on the comet's nucleus and collect information to send back home.

This material is provided through the courtesy of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

ABOUT THE PICTURES ON THE FRONT

The Space Technology 4/Champollion mission is due to be launched in 2003, heading for Comet Tempel 1. Flying alongside the comet, it will map the nucleus before sending a small probe, the Champollion lander, to touch down on its surface.

This artist's rendering envisions the scene after the Champollion lander has attached itself to the comet nucleus and begun collecting and analyzing samples and taking pictures of the surface.

ST4/Champollion is pleased to share the excitement of this mission with the University of Southern California and its Summer Space Seminar.

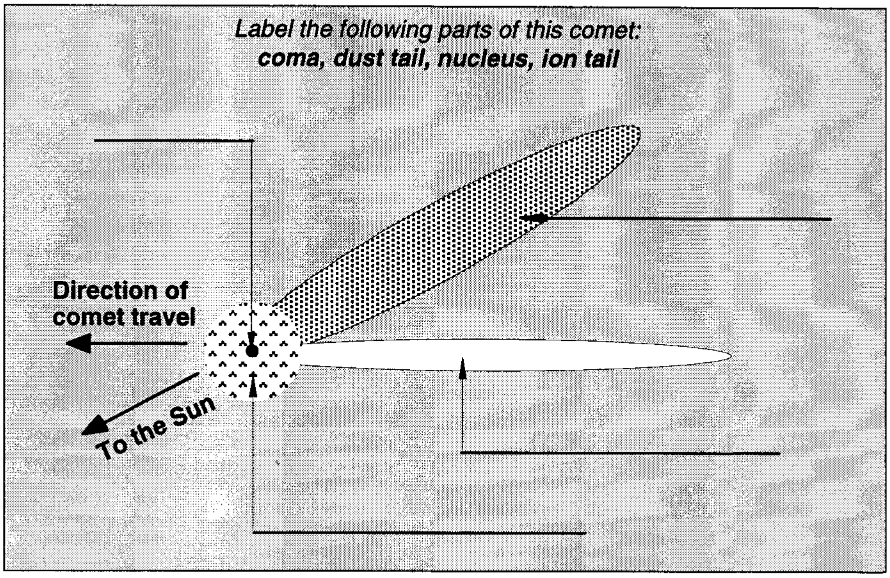
INTERESTING FACTS ABOUT COMETS

ORIGINS: Astronomers have identified a region in space, near the edges of our solar system, where trillions of comets reside. This area is called the Oort Cloud. Even though six trillion miles (1 light year) away, these comets orbit the Sun, influenced by its gravity. The Kuiper Belt, more or less in the same plane as the planets and beyond the orbit of Pluto, is another region where comets reside. Gravitational influences of nearby stars outside our solar system, or, in the case of Kuiper Belt comets, gravitational influences of the planets within the solar system, can occasionally perturb the orbit of one of the icy rocks, flinging it toward the Sun. As it approaches the inner solar system, it begins to heat up and develop the characteristic coma and tails that we may see from Earth.

TYPES: Comets are categorized into two types according to the time they take to orbit the Sun. This time is called a comet's *period*. Short-period comets take 200 years or less to go around the Sun, while long-period comets take longer than 200 years. Of the more than 875 comets discovered so far, about 180 are short-period comets. One of the most famous of these is Comet Halley, which is visible from Earth every 76 years as it completes one more orbit around the Sun.

ACTIVITY 1: THE STRUCTURE OF A COMET

What makes a comet a comet? Why aren't comets considered to be planets if both bodies travel around the Sun? Comets aren't considered planets because they are different in size, composition, structure, and in the way they orbit the Sun.



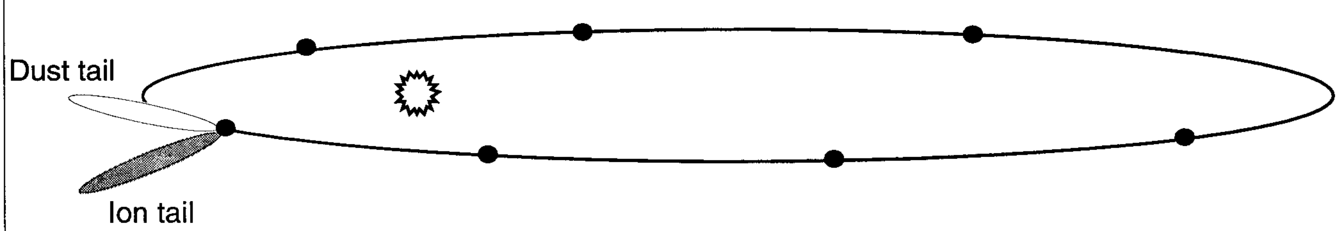
Studies done so far on comets show they have a distinct structure that changes according to their location in relation to the Sun. When the comet is far away from the Sun, it is a frozen ball of rock and dirty ice flying through the vacuum of space. When it comes closer, the heat from the Sun begins to melt the frozen gases, which leads to the formation of a comet's tails. One tail is made of ionized gases and is blown directly away from the comet by the solar wind, a continuous stream of ionized atoms and electrons flowing outward from the Sun. The other tail is made of heavier dust particles which are not blown quite as far and tend to remain closer to the comet's path. Notice the pictures of comets on the front of the poster. See if you can identify their ion tails and dust tails .

As a comet nears the Sun, its tails grow longer. The main mass of a comet is called the *nucleus* and is believed to contain a mixture of ice and rock. As the Sun heats it up, the ice vaporizes and forms an atmosphere, called a *coma*, surrounding the nucleus. The solar wind is strong enough to push this atmosphere behind the comet to form its ion tail. Learning exactly what the comet's nucleus is made of is very important to scientists, because comets are remnants of the material that formed our solar system. Their large orbits, which keep them far away from most bodies in the solar system, have enabled them to remain largely unchanged for 4.5 billion years.

While comets and planets were formed around the same time 4.5 billion years ago, they differ greatly in many respects.

The nucleus of a comet is quite small compared to a planet. Planets in our solar system range from 2300 kilometers (1380 miles) across (Pluto) to 143,000 kilometers (85,800 miles) across (Jupiter), whereas all comet nuclei are typically smaller than 10 kilometers (6 miles) across. The reason comets can become so visible in spite of their size is because their comas can be four times the size of Earth and their tails can grow to millions of kilometers long.

This is a drawing of a comet's path around the Sun. Draw the ion tail (where needed) and the dust tail for each of the comet's positions shown here. One position has been drawn as an example. Keep in mind the comet's tails get longer when the comet gets closer to the Sun and are short to nonexistent when farther away. Also, remember the ion tail points directly away from the Sun, while the dust tail tends to be aligned closer to the comet's previous path. (The tiny ion particles are blown away more easily than the larger, heavier dust particles.)

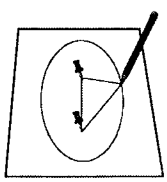


Activity 2: Charting the Orbits of Comets

One of the many things that makes a comet different from a planet is its orbit around the Sun. Planets in our solar system tend to orbit the Sun in nearly circular paths. Comets, however, have very elongated orbits, with one end coming very near the Sun and the other end very far from the Sun.

Tie a 20-centimeter (8-inch) length of string into a loop. Push a pin into a piece of cardboard. Place the loop of string around the pin. Use a pencil inside the loop to trace out a shape as you pull the loop tight. What shape is made with one pin at the center?

Place a second pin 5 cm (2 in) from the first pin. With the loop of string enclosing both pins, trace another shape with the pencil. This shape is called an *ellipse*. How is this shape different from the first shape?



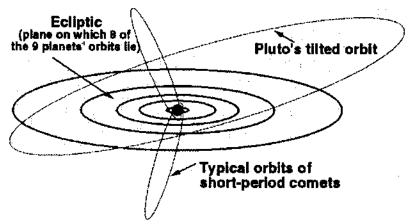
A circle has a single center, but an ellipse has two centers, called foci (FO-SIGH). The pins represent the foci of the ellipse you have drawn.

Move one of the foci so it is 8 cm (3 in) from the other one. Trace a loop with the pencil. How did the shape of the ellipse change?

The amount of flattening of the ellipse is called its *eccentricity*. A circle is a special kind of ellipse with no flattening, so we say it has an eccentricity of 0 (zero). An ellipse that is so flat it looks almost like a straight line has an eccentricity of almost 1.

The orbit of anything that orbits the Sun has two foci, with the Sun at one and empty space at the other. As it nears the Sun, the comet's path is bent by the increasing pull of the Sun's gravity until the comet swings around the Sun and heads back into deep space. Sometimes, comets come so close to the Sun, they just crash into it, instead of swinging around it.

Comets' orbits differ from those of planets not only in their shape (eccentricity), but also in their orientation. All planets' orbits lie very close to an imaginary flat plane called the *ecliptic*. In fact, all planets even orbit the Sun in the same direction. The orbits of comets, on the other hand, are tilted at random angles to the ecliptic.



In the second part of this activity, we will draw the orbits of the solar system. We will include the planets and a few comets. Except for Pluto, the planets' orbits have such a small eccentricity, we will draw their orbits as circles. We can draw Pluto's more eccentric orbit as similar to the orbits of comets using the two foci method we used before.

We will need lots of room for this drawing if the orbits are to be to scale. Let's go outside and draw with chalk on some pavement, so we can really get a feel for some distances.

You will need:

- Area of pavement outside at least 8 m (27 ft) by 6 m (20 ft)
- Sidewalk chalk, two colors
- Two broom or mop handles (rubber tips are helpful)
- String
- Meter (yard) stick or tape measure
- Small pieces of paper (for labels)
- Stapler

First, draw the orbits of the first eight planets:

1. Cut pieces of string for each orbit with the lengths (either in centimeters or inches) given in the table below. (These measurements already include an extra 15 cm [6 in] for tying a knot and looping the string around the broom handle.)

Orbit of Planet . . .	String Length (cm)	String Length (in)
Mercury	25	10
Venus	29	11.5
Earth	35	14
Mars	49	19.5
Jupiter	125	50
Saturn	215	86
Uranus	415	166
Neptune	615	246

2. Tie each length of string into a loop. Write the planet name on a small piece of paper and staple it to the string.

3. Mark a spot on the pavement to represent the position of the Sun. Have one person stand the end of the broom handle on this spot.

4. Anchor the loop at the broom handle. Use one color of chalk for all the planets' orbits. With the chalk inside the loop, stretch it all the way out and draw a circle. If the Mercury and Venus loops seem too small to work with, first draw the Earth orbit, then free-hand sketch in the two smaller orbits, using the lengths of their loops as an eyeball guide.

Draw the rest of the planets' orbits through Neptune. For the outer orbits, be sure to keep that string stretched tight! These orbits are *big*!

Now, draw orbits for Pluto and some short-period comets:

1. Make loops of string with lengths given in the "string length" columns of the table below. Label them as you did for the planets' orbits.

Orbit for ... (Comet period)	String Length, cm (in)		Foci distance, cm (in)	
Pluto	1015	(406)	200	(80)
Comet Encke (3.3 yrs)	95	(38)	38	(15)
Comet Halley (76 yrs)	715	(286)	340	(136)
Comet Tempel 1 (5.7 yrs)	110	(44)	33	(13)
Comet Giacobini-Zinner (6.5 yrs)	135	(54)	50	(20)
Comet Tuttle (13.5 yrs)	215	(86)	90	(36)

2. For each orbit, in addition to a broom handle placed at the Sun position, place a second broom handle at the foci distance given in the chart.

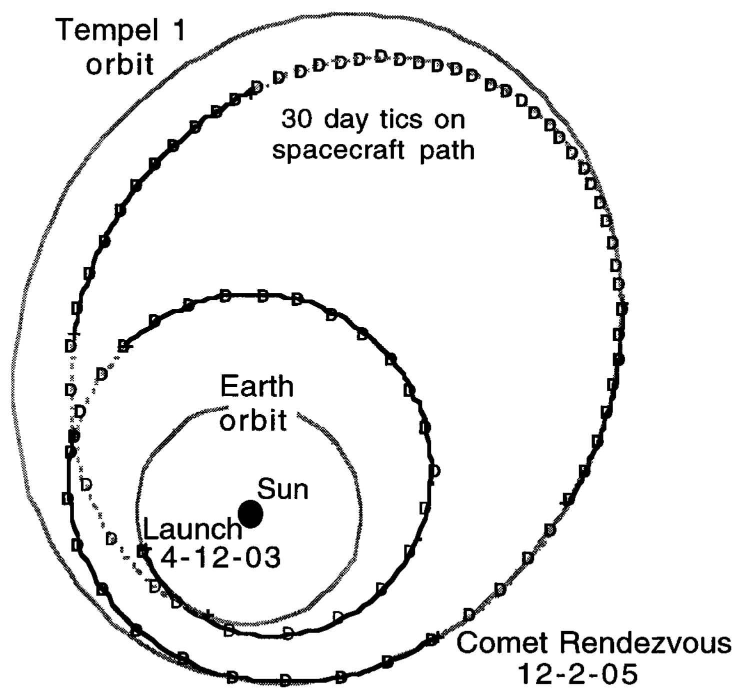
3. Using the second color of chalk for the comet orbits, draw the elliptical orbits using the loops with the two broom handles as foci.

What is unique about Pluto's orbit compared to Neptune's, the next planet in toward the Sun? How are the orbits of short-period comets different from those of the planets? Long-period comets have orbits that stretch far beyond Pluto's orbit and can take over 10,000 years to orbit the Sun just once. Their orbits are much too large and elongated to fit on your pavement, even if it covered the entire campus!

NASA/JPL's New Millennium Program and Space Technology 4/Champollion

Space Technology 4/Champollion is the fourth interplanetary mission of the National Aeronautics and Space Administration's (NASA's) New Millennium Program (NMP). This program will send a series of spacecraft with experimental systems and instruments into deep space and into orbit around Earth to see if they work. Although the primary aim of all New Millennium missions is to test new technology, they will also collect and return scientific data from a variety of solar system bodies.

The NMP missions will test these advanced technologies by carrying out exciting and challenging scientific investigations never attempted before. Not only will these missions thoroughly test the technologies, they will also allow NASA's engineers to see whether these new systems and instruments can carry out the complex tasks required of them during similar, perhaps even more scientifically intense mission scenarios in the future.



This trajectory shows the path ST4/Champollion will follow to reach Comet Tempel 1.

For many years comets have been studied from far away. But scientists would like to learn much more about them, and many of their questions can be answered only by getting very close to a comet and studying it in detail. This is why NASA is preparing to launch the Space Technology 4/Champollion mission. In 2003, this spacecraft will be sent to study Tempel 1, a comet that orbits the sun every five and one-half years, with its entire elliptical orbit falling between the orbits of Earth and Jupiter. When it reaches the comet in late 2005, it will *rendezvous* with (fly alongside) the comet in its path as it moves away from the Sun. Circling Tempel 1's six-kilometer (four-mile) diameter nucleus for several months, ST4/Champollion will make highly accurate maps of its surface and take some preliminary measurements of the composition of the gas in the coma (the halo which surrounds the nucleus). The data sent back to Earth by ST4/Champollion will allow scientists to find out the mass, shape, and density of the comet's nucleus.

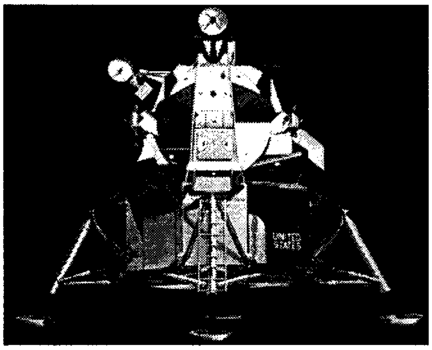
After studying the comet from some distance, the spacecraft will release a small probe, the Champollion lander, to travel to the surface of the nucleus. Its touchdown will be a challenging feat for engineers, since they do not know what the comet's surface is made of, whether it is hard and rocky or soft and fluffy. They have to design technology and instruments for the lander that will work in any situation. One design the engineers have created is a harpoon that will be shot into the nucleus to anchor the lander while it drills for a sample of cometary material.

Once the lander has acquired a bit of the nucleus, instruments onboard will examine its structure and analyze its composition, while cameras photograph the area surrounding the lander and other instruments test the strength and other physical properties of the surface. Scientists and engineers will be closely monitoring the lander during the three and one-half days it stays on the nucleus.

The Space Technology 4/ Champollion mission is managed for NASA by the Jet Propulsion Laboratory, which is part of the California Institute of Technology.

Activity 3: Designing a Vehicle to Land on a Comet

Exploring new regions of the universe requires NASA engineers to design spacecraft that can adapt to new and unforeseen conditions they may encounter during their missions.



Apollo Lunar Lander

To land astronauts on the Moon, NASA developed special technologies to allow the spacecraft to touch down on the Moon's surface. The Moon does not have an atmosphere like Earth, so spacecraft could not land by floating down with a parachute, or by gliding in with wings. Rocket jets gently lowered the Apollo landers to the surface of the Moon against the pull of the moon's weak gravity. Large, round pads supported the lunar lander and kept it from sinking too far into the lunar soil. Once on the moon's surface, the lander was held in place by the moon's gravity.

Techniques for landing spacecraft back on Earth have matured from the parachute-capsule method used by the Apollo lunar missions that welcomed the astronauts back to Earth with a jolting splashdown in the ocean. Now, the Space Shuttle, which allows a much larger payload, uses a reusable winged glider to gently land on an airport runway.

Mars Pathfinder Parachute and Retro-rocket Landing System

The recent Mars Pathfinder mission demonstrated yet another technique for landing on a foreign surface. Its payload was a mechanical robot, so it could withstand a more severe shock upon landing than could a human passenger. NASA engineers used a combination of parachute and retro-rockets to lower the Pathfinder through Mars' thin atmosphere. Airbags surrounding the lander then inflated to provide a soft cushioning effect when the lander bounced onto Mar's surface.

The problem of landing on a comet will be even more difficult than landing on the surface of the Moon or Mars. Scientists are not certain what the surface of a comet's nucleus is made of. It could be as hard as concrete or soft as cotton candy. The surface could also be rougher than a lava field or as smooth as an ice-covered lake. An even more important issue is that, because it is so small, there is much less gravity on a comet than there is on Earth or the Moon. Without gravity to hold it down, a spacecraft that landed on a comet would drift away back into space.

In this exercise, you will brainstorm about the design issues that may arise in building a vehicle to land on a comet and come up with possible solutions to address those issues. Then you will compare your ideas to those of NASA's engineers in their design of the ST4 lander, Champollion.

1. Describe how you would deal with each of the following challenges in landing on a comet:
    a. Getting the spacecraft from Earth to a comet in orbit between Mars and Jupiter.
    b. Landing on a rocky comet surface harder than concrete.
    c. Landing on a snowy or dusty comet surface as soft as cotton candy.
    d. Keeping the comet lander in place on the surface of the comet without gravity pulling down on it to keep it there.
    e. Returning a sample of the comet back to earth for further study.

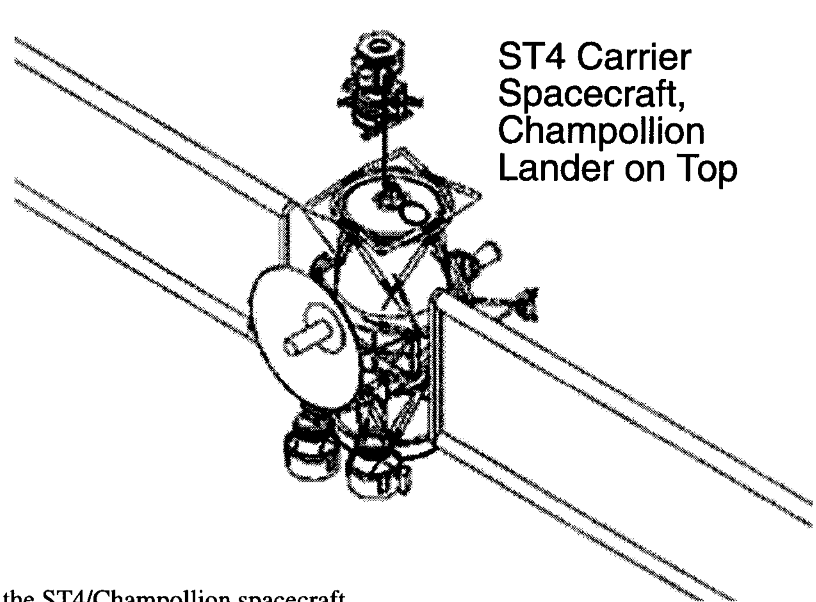
2. Compare your solutions for each of the challenges listed above with those from four or five of your class-mates. As a team, select the best solution for each of the challenges from the entire group keeping in mind that the final spacecraft will have to be fairly simple, rugged, and small in order to keep the weight, and therefore cost, of the entire mission down and within budget.

3. As a group, make a drawing of your completed design on poster paper. Present your proposal to the other teams in the class describing how each part of your design meets one of the challenges listed above.

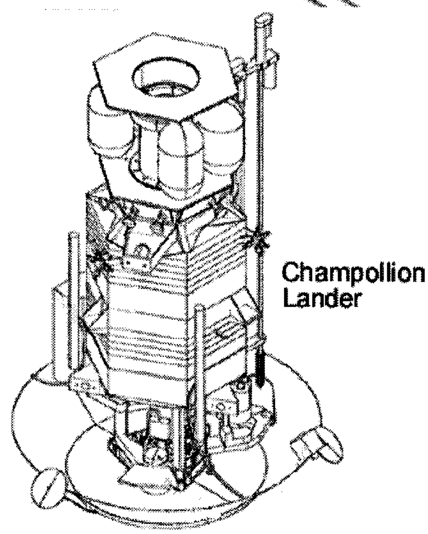
4. Compare your design to the ST 4/Champollion lander shown on the next panel, "How did JPL do it?" Which aspects of your design are similar to the design by JPL/NASA engineers? Which are different?

5. Congratulate yourself and your teammates on a job well done!

How JPL Did It:
Space Technology 4/Champollion

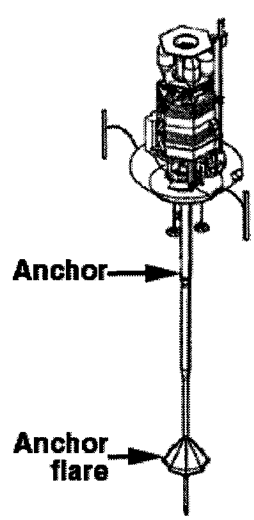


Jet Propulsion Laboratory engineers designed the ST4/Champollion spacecraft in two parts, an orbiting carrier spacecraft and a lander. A large rocket will launch them as a single unit. The spacecraft will travel to the comet using a new type of ion engine that operates by electricity generated from solar panels. The flight will take two and one-half years to reach the comet, which will be at 2.5 Astronomical Units from the Sun (that is, two and one-half times the distance from Earth to the Sun). The orbiting "mothership" will act as a communications hub between the lander and Earth. After nearing Comet Tempel 1 and studying it for a few weeks, the orbiter will release the lander. The lander will make its way to the surface of the comet using tiny reaction control rockets like those used to help point the Space Shuttle.



As the Champollion lander touches down on the comet, sensors on the bottom of the lander activate a gas generating device, which causes a 3-meter (10-foot) long telescoping harpoon, called the anchor, to fire into the comet. The harpoon will hit the comet surface at 150 meters (500 feet) per second, fast enough to penetrate the hardest rock.

If the surface of the comet is soft, an umbrella shaped anchor flare will deploy at the end of the anchor to hold Champollion down in the absence of gravity. The entire lander is about 1.5 meters (5 feet) tall, .75 meters (2.5 feet) wide, and weighs—on Earth—120 kilograms (264 pounds). It will operate for three days on battery power and conduct many experiments to test the surface conditions and composition of the comet using equipment such as a gamma ray detector, 3-D cameras, microscopes, a gas chromatograph, and a surface properties instrument. All these instruments are mounted on a turntable to allow samples from the comet to be drilled from different depths and locations around the spacecraft.



The JPL comet lander design represents a new approach to space exploration, emphasizing smaller, faster, and cheaper spacecraft that accomplish fewer, more specific goals, but at a much more affordable price.

How did your own comet lander design compare to the one made by JPL engineers?

TEACHER'S GUIDE

The materials presented on the back of this poster are intended for use in the middle-school and high-school classroom. The eight panels are designed to be photocopied and handed out to students and completed as assignments.

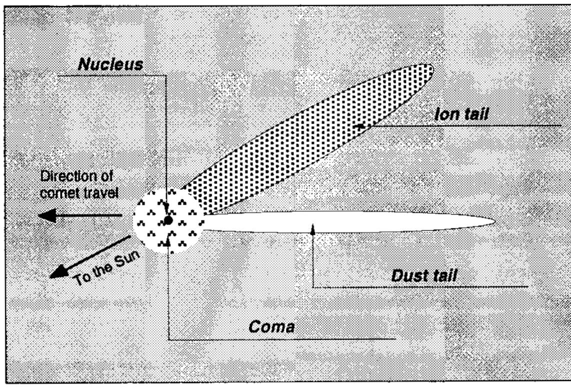
Activity 1 can be given out as a worksheet for students to complete. The solutions are given in the boxes below.

Activity 2 can be done as a lab. It introduces the concepts of the shape of orbits and progresses from circles, which have one center, to ellipses, which have two centers.

Drawing the orbits of the planets on a large scale makes the comparison of the relative sizes of the orbits of the inner vs. outer planets quite dramatic. Note that because of its eccentricity, Pluto's orbit intersects Neptune's orbit and for a short while, Pluto is actually inside of Neptune's orbit! Comet orbits tend to be very elongated, especially those of long period comets. Orbits of the short period comets are generally inside Jupiter's orbit.

Activity 3 is a thought exercise that is especially suitable for group work. Students can simulate being on a mission design team and compete for the best design in the classroom. Compare the students' results with the JPL design shown in the adjacent panel.

For further information, check the ST4/Champollion Web site at **http://nmp.jpl.nasa.gov/Champollion/** .



Is this comet near the sun or far away? Why?

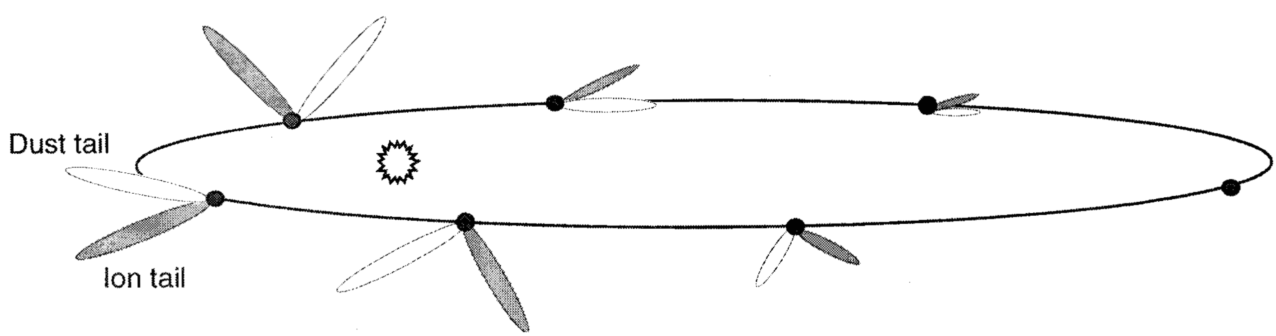
The comet is near the sun because the tails of the comet are starting to grow long. The sun's heat and the solar wind cause the tails to grow only when the distance between the sun and comet are smaller.

WHAT'S IN A NAME?

COMET TEMPEL 1: Named after Ernst Wihelm Liebrecht Tempel, of Marseille, France, who discovered this comet in 1867. It orbits the sun once every 5.68 years. The closest Tempel 1 has approached Earth is about half the distance between the Earth and the Sun (70 million kilometers).

CHAMPOLLION: Name of the French archeologist who deciphered the Rosetta Stone, an ancient stone tablet written in three languages. The Rosetta stone helped archeologists to decipher the alphabet of the forgotten languages, allowing new insights into previously unreadable text. Just as Champollion helped to usher in a new age of study of ancient civilizations, the ST4/Champollion mission will help unlock the secrets of the formation of our solar system.

This is a drawing of a comet's path around the Sun. Note that the tail is almost nonexistent far from the sun and grows longer as the comet nears the Sun. The dark shaded tail is the ion tail, which points directly away from the Sun. Note also that empty space is at the other (non-Sun) focus of the ellipse.



Space Science Summer Seminar

Students of the USC Summer Seminar in Space Science take courses in planetary geology, science fiction, physics, and astronomy taught by the renowned research faculty of USC's College of Letters, Arts, and Sciences. They also have the opportunity to gain hands-on research experience at NASA's Jet Propulsion Laboratory. (Students of the 1998 Space Science Seminar did research at the Extraterrestrial Materials Simulation Laboratory—a JPL laboratory of central importance to the planning of the ST4/Champollion mission.)

The four week seminar's unique combination of science and the humanities challenges its students to think about the Universe critically and imaginatively. The Space Science Seminar is an incredible opportunity not only to study with leading scholars from the College of Letters, Arts, and Sciences, but also to apply what is learned in the classroom and laboratory to real-life challenges faced by NASA.

For information about the Space Science Summer Seminar and other seminars offered by USC's Summer Seminar Program call 213/740-5679. You can also send email to summer@usc.edu and visit our Web page at:

http://www.usc.edu/dept/provost/ugstudies/seminar.html

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College of Letters, Arts, and Sciences

When you think about "going to college," you probably think about a place where you'll be challenged to make sense of the most stimulating books, the most provocative current research, and the most mind-boggling insights into the world we've inherited and the world we've made. At USC, the place you'll confront the basic questions behind the arts and sciences is the College of Letters, Arts, and Sciences.

The College is the liberal arts center of USC. It combines two "worlds"—the world of the self-contained liberal arts school, with small classes and close working relationships between student and faculty, and the larger world of the research university, where new ventures and new ideas are being explored.

In the College you'll find majors and minors to suit all your interests, to broaden your horizons, and to help you fulfill your career goals. If learning about the Space Technology 4/Champollion mission has made you want to be a scientist and do research of your own, we invite you to explore the Web sites of our departments of Biological Sciences, Chemistry, Earth Sciences, Exercise Science, Mathematics, Physics and Astronomy, and of our Environmental Studies and Psychobiology programs. For all departments in the College, including those offering majors and minors in the humanities and social sciences, visit the College Home Page at:

http://www.usc.edu/dept/LAS/Main